

Hypercharged Conformally Sequestered Gauge Mediation

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ABSTRACT: The $B\mu/\mu$ solution in GMSB via the hidden sector dynamics is simple and natural. However, it has some obstacles to be physical. To circumvent this situation, we introduce the visible and the hidden branes, each of which has its own $U(1)$ symmetry, in a five dimensional setup. In the bulk we allow Chern-Simons coupling between the visible and the hidden $U(1)$ s which gives an enhancement of the mass of bino. If this gives a considerable contribution to the mass of bino, we can get a proper radiative electro weak symmetry breaking with the boundary conditions, in which $B\mu$ and squared scalar masses are suppressed at the scale, where the hidden sector is integrated out.

KEYWORDS: MSSM, μ problem in GMSB, RG effect of the Hidden Sector.

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1. Introduction

Sequestering is a mechanism that can suppress the amplitudes of the unwanted operators. This is usually used when we want to suppress the tree level flavor changing neutral current (FCNC) in the mediation mechanism, where the gravity may have a significant contribution. It can be understood in the geometrical sense via the string theory [1]. Sequestering gives a number of interesting phenomenological features so it is worth studying.

There are a variety of mediation mechanisms in MSSM. Among them the most famous ones, which are free from FCNC problem are gauge mediated supersymmetry breaking (GMSB) and anomaly mediated supersymmetry breaking (AMSB). In GMSB, generating an electro weak scale μ is not serious by itself however, the requirement for the low energy electro-weak symmetry breaking (EWSB) makes a very unnatural situation [2]. Among a number of possible explanations to ameliorate this [3, 4, 5], the sequestering idea suggests a very simple solution [4, 5]. By the way, once the information of the hidden sector renormalization effect is imposed, we have an additional effect: the gravitino has an enhanced mass. This aspect also makes the sequestering idea interesting in GMSB. The idea to solve $B\mu/\mu$ problem in GMSB via the conformal sequestering is clear and simple. However, the simplest form appears not to have physical case, i.e. it does not seem to provide a physical solution to a proper EWSB [6, 9]. It is because the boundary conditions given at an intermediate scale have relatively small scalar squared masses including higgs. When we follow along the MSSM RG equation, it is hard to satisfy the EWSB conditions. In other words, the parameter space where we have a proper EWSB is not compatible with the boundary conditions at the intermediate scale. Therefore some modification to the simplest case is necessary. Here we consider the 5 dimensional setup. We introduce two 3 branes: one is where the visible sector resides and the other is for hidden sector. We introduce $U(1)_h$ at the hidden brane and a five dimensional Chern-Simons coupling in the bulk. As an effect of five dimensional Chern-Simons term, the mass of bino on the visible brane is enhanced. This is the idea in [11] to solve the tachyonic slepton

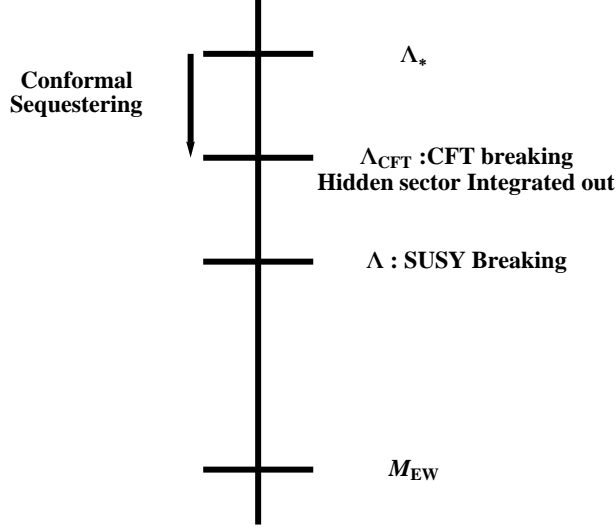


Figure 1: Scale and the dynamics of Ref.[4, 5]

problem in a pure AMSB setup. Just like [11], in this setup, all the scalars charged under $U(1)_Y$ get the radiative correction by the mass of bino. With a numerical study we find a physical solution, i.e. get a proper EWSB.

This paper is organized as follows. In section 2, we discuss on the sequestering in GMSB. In section 3, we take the viewpoint of the five dimensional setup and introduce a Chern-Simons term in the bulk to find a physical solution. In section 4, we discuss the phenomenological implication. Finally we make a conclusion.

2. Sequestering in Gauge Mediation

Strictly speaking, sequestering in GMSB is not a necessary condition to circumvent FCNC problem because supersymmetry breaking occurs at a rather low energy scale so that undesirable gravity contribution is negligible. The role of sequestering in GMSB, however, appears to be interesting and attractive because of its unique feature[10]. In GMSB there is a problem known as $B\mu/\mu$ problem, and it is recently suggested that if we consider the sequestering effect in GMSB, then we can solve $B\mu/\mu$ problem [4, 5]. Here we will briefly review the idea of sequestering as a solution to $B\mu/\mu$ problem. In the supersymmetry conserving part, μ is the unique dimensionful parameter so that it is necessary to link it with supersymmetry breaking to ensure the low energy supersymmetry. In GMSB, it is possible to introduce the superpotential as

$$W = \lambda X \mathbf{10} \cdot \bar{\mathbf{10}} + \xi_d H_d \mathbf{10} \cdot \mathbf{10} + \xi_u H_u \bar{\mathbf{10}} \cdot \bar{\mathbf{10}}, \quad (2.1)$$

where $\mathbf{10}, \bar{\mathbf{10}}$ are messenger fields, X denotes the field which breaks supersymmetry and, λ and $\xi_{u,d}$ are $\mathcal{O}(1)$ appropriate dimensionless couplings. After integrating out the massive messenger fields,

we get

$$\begin{aligned}
\mu &\sim \frac{\xi_u \xi_d}{16\pi^2} H_1 H_2 \left(\frac{M^\dagger}{M} \frac{F^\dagger}{M^\dagger} \right) = \frac{\xi_u \xi_d}{16\pi^2} \Lambda \left[1 + \mathcal{O}\left(\frac{F^2}{M_{mess}^4}\right) \right], \\
B_\mu &\sim \frac{\xi_u \xi_d}{16\pi^2} H_1 H_2 \left(\frac{M^\dagger}{M} \left(\frac{F F^\dagger}{M M^\dagger} \right) \right) = \frac{\xi_u \xi_d}{16\pi^2} \Lambda^2 \left[1 + \mathcal{O}\left(\frac{F^2}{M_{mess}^4}\right) \right] = \Lambda \mu, \\
A_{H_{1,2}} &\sim \frac{\partial \log Z_{H_{u,d}}}{\partial \log X} = \frac{-\frac{|\xi_{u,d}|^2}{16\pi^2}}{1 - \frac{|\xi_{u,d}|^2}{16\pi^2} \log X X^\dagger} \frac{F}{M} \sim -\frac{|\xi_{u,d}|^2}{16\pi^2} \frac{F}{M}, \\
m_{H_{u,d}}^2 &\sim \frac{\partial^2 \log Z_{H_{u,d}}}{\partial \log X \partial \log X^\dagger} = -\left(\frac{|\xi_{u,d}|^2}{16\pi^2} \right)^2 \frac{1}{(1 - \frac{|\xi_{u,d}|^2}{16\pi^2} \log X X^\dagger)^2} \frac{F F^\dagger}{M M^\dagger} \sim -\left(\frac{|\xi_{u,d}|^2}{16\pi^2} \right)^2 \frac{F F^\dagger}{M M^\dagger},
\end{aligned} \tag{2.2}$$

Here we see $B\mu = \Lambda\mu$, which is undesirable for the phenomenological requirement. This is the $B\mu/\mu$ problem in GMSB. Here we see that the relation between A and μ , i.e. $A_u A_d = |\mu|^2$. Not to conflict to the perturbation, the coupling $\xi_{u,d}$ should not be large. For a convenience, we take $\xi_u = \xi_d$, but later we will consider a general case in range, where the perturbation of the messenger coupling is guaranteed.

The basic idea to solve this problem, which we concern, is using the 1PI effect on the propagator of X in the strongly interacting hidden sector. As a result, the operators which are proportional to XX^\dagger are suppressed relative to those which are proportional to either X or X^\dagger . The operators for supersymmetry breaking masses are generated at the original messenger scale just in the case of usual GMSB setup. As we go down to low energy, the theory goes through a conformal window. At an intermediate scale Λ_{CFT} , the conformal symmetry is broken and the supersymmetry breaking operators get their values, which are affected by the hidden sector RG effect described above. This imposes that $B\mu$ can be made of $\mathcal{O}(\mu^2)$ or smaller, therefore $B\mu/\mu$ problem in GMSB can be solved with a simple assumption. In addition to this, there can be another effect, coming from the anomalous dimension of X ,¹ which makes the masses of ordinary superpartners suppressed relative to the mass of the gravitino. In other words, the amount that the gravitino feels by supersymmetry breaking is not the same as the others.

Here we want to make it clear whether this mechanism spoils the nice feature of GMSB in solving FCNC problem or not. The gravitational contribution to soft breaking parameters appears to be proportional to the mass of gravitino, which can be a source of the FCNC problem. As denoted above, the gravitino mass is enhanced by the hidden sector RG effect and the gauge contribution suppressed by a factor of anomalous dimensions. Here we can see that a tension between FCNC and $B\mu/\mu$ problem. As denoted in [5] if the gravity contribution is enhanced, then one of the virtues of GMSB is lost. Since the problematic contribution to FCNC appears in soft scalar mass squares, we should be careful about this inequality,

$$m_{gravity}^2 \sim \frac{F^\dagger F}{M_P^2} = m_{3/2}^2 < m_{gauge}^2. \tag{2.3}$$

¹This anomalous dimension should be considered independently i.e. the effect which suppresses the operators containing XX^\dagger is another. To make this difference clear, see [5, 9]

By the language appearing in [5], the constraint on the mass parameters is given by

$$\frac{(16\pi^2)^2}{\lambda^2} \frac{M_{mess}^2}{M_p^2} \left(\frac{\Lambda_*}{\Lambda_{CFT}} \right)^{2\gamma_X} < \mathcal{O}(1), \quad (2.4)$$

where λ is the coupling given in (2.1), Λ_* is a scale where the hidden sector gets conformal and γ_X is an anomalous dimension of X . This can be easily satisfied if $\left(\frac{\Lambda_*}{\Lambda_{CFT}} \right)^{2\gamma_X}$ is not large.

Now we investigate the low energy physics with a numerical tool.

$$\begin{aligned} m_i &\sim \frac{\alpha_i}{4\pi} \Lambda \quad (i=1,2,3), & A_{H_{u,d}} &\sim -\mu, \\ m_\phi^2 &\sim 0, & m_{H_{u,d}}^2 + \mu^2 &\sim 0 \end{aligned} \quad (2.5)$$

² With these boundary conditions, we use **softsusy** to investigate the low energy spectrum [13]. The idea is very simple and natural however, it appears to have an unnatural situation in RG improved studies [6, 9]. In the MSSM RG equations, we see the scalar masses are determined by the gaugino contribution, the trilinear terms and their masses. In this analysis, we just use the value of μ , which is given by the low energy requirement, that is we can not handle μ and $A_{u,d}$ at Λ_{CFT} . This makes the analytic approach to this problem difficult. Since $A_{u,d}$ grow via mainly the gluino contribution and give considerable radiative correction to higgs mass because of large yukawa couplings especially top yukawa at small $\tan\beta$ region. From the RG equation of MSSM, we see that gauginos give positive contribution and, $A_{u,d}$ and scalar masses give negative contribution to higgs masses as we go down to the low energy scale. Since $A_{u,d}$ get larger than wino and bino, the higgs masses can get negative. On the other hand, because of A_l , the lightest stau gets negative squared mass, which is not favored. If we restrict $B\mu$ to a positive definite quantity at the low energy scale in order not to have a tadpole problem, $B\mu/\mu$, which is under the control of only gauginos and $A_{u,d,l}$ can grow large enough to threaten the stability of the higgs potential in some parameter space. Unfortunately $B\mu$ is also a given quantity in this analysis, we check whether it is from the boundary condition, which we assume at Λ_{CFT} . And the result was the boundary condition is not compatible with the low energy physics [6]. It also appears that it is hard to make things better if Λ is larger than about 200TeV. Though it is not easily seen, if we have a large Λ , then all the soft terms get the radiative corrections from rather massive gauginos, of which masses are proportional to Λ at Λ_{CFT} . As denoted above, the gluino gives large correction to $A_{u,d}$ so that $B\mu$ gets negative at electro weak scale. In [9], the authors try to evade this problem by introducing additional messenger masses by an adjoint chiral multiplet, which is supposed to break the grand unified theory. As a result, they are free from that unnatural situation however, the scalar masses appear small so that the experimental bound might be dangerous. In the next section, we suggest another way out.

²There is a confusion on this boundary conditions [7, 8]. Since μ and A are generated via supersymmetry breaking F terms, a survey on the effective Kahler potential shows that higgs mass is given as $m_h^2 + |\mu|^2$. By the hidden sector RG effects higgs masses is vanishes like the other scalar.

3. Introducing a Chern-Simons Term in the Bulk

Recently, it is found that a hidden $U(1)_h$ has interesting phenomena in the low energy physics. Among a number of solution to solve the tachyonic slepton problem, there is a study where hidden $U(1)_h$ takes an important role [11, 12]. There they consider two three branes, which have their own $U(1)$ gauge theory: $U(1)_v$ for the visible brane and $U(1)_h$ for the hidden brane. In the five dimensional bulk we introduce a Chern Simons coupling $\int C_{p-1} \wedge tr F$, where C_{p-1} is Ramond-Ramond $p-1$ form in the bulk. As a result, two $U(1)$ gauge fields get mixed, so that there can be two linearly independent combinations. One of them remains massless, which will be $U(1)_Y$, and the other gets massive. By this mechanism, bino can get an additional contribution, and the scalar partners of fermions as well as the higgs get radiative correction

$$\delta m_i^2 = -\frac{3}{10\pi^2} g_1^2 Y_i^2 M_1^2 \log \frac{\mu}{M}. \quad (3.1)$$

Therefore, the boundary condition at UV scale can be changed. Here we want to do the same job in the conformally sequestered GMSB setup.

$$\begin{aligned} m_i &\sim \frac{\alpha_i}{4\pi} \Lambda, \quad (i=2,3) & A_{H_{u,d}} &\sim -\mu, \\ m_\phi^2 &\sim 0, & m_{H_{u,d}}^2 + \mu^2 &\sim 0, \\ m_1 &\sim \frac{\alpha_1}{4\pi} \Lambda + (\text{enhancement by CS interaction: } \tilde{M}) \end{aligned} \quad (3.2)$$

Then we use a package **softsusy** again to check whether our modification works. For simplicity, we will consider Λ_{CFT} to be close to the original messenger scale because we do not want to consider the visible sector RG effect. This also help us to consider the more suppressed case than a naive expectation of $16\pi^2$, because it can minimize the possible visible sector contribution. The boundary condition (3.2) is used at the effective messenger scale, and below that scale, it is a good approximation to use MSSM RG. We set the effective messenger scale as 10^{12}GeV , varying $\tan\beta$ and Λ . The important ingredient is the mass of bino correction from CS interaction. This depends on our choice, and we assume that it is order of $\frac{\mu}{M} \sim \mathcal{O}(1)^3$. One question may arise on the additional CP phase. Though we assume that supersymmetry breaking is up to a single field X , there can be a misalignment between other gauginos and bino so that there can exist the additional CP phase. For simplicity, however, we assume there is no additional CP phase. With these boundary conditions, we run **softsusy**.⁴

In the right panel of Fig. (2) we see that there exists parameter space where the low energy EWSB requirements and the consistency of mechanism are satisfied. The region can be changed, when we allow correction to the mass of bino, i.e. this can be tuned by appropriate \tilde{M} and suppression factor, which is given as boundary conditions at Λ_{CFT} . To see the effect of \tilde{M} , here

³Unlike the original idea, the gravitino mass is not an order parameter in this case. So we make a use of μ , which is made for a proper EWSB.

⁴There can be an error of $\pm 3\text{GeV}$ theoretically in the spectrum calculating packages, so we allow 3GeV difference in the higgs mass [14].

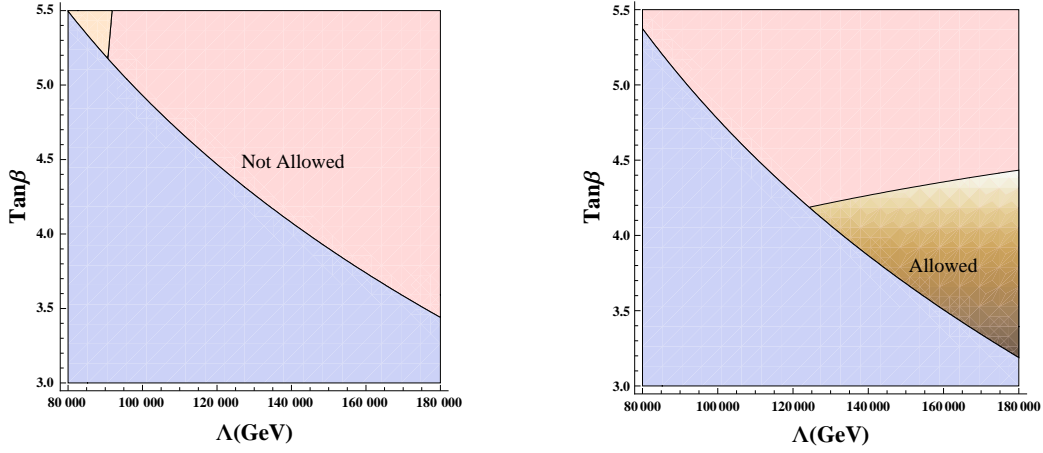


Figure 2: We choose $\Lambda_{CFT} = 10^{12}\text{GeV}$ and set sign of μ to be positive. The blue region is excluded by the mass bound for lightest higgs, the red by the inconsistency and the orange by the stau mass bound. The left panel is the result of $\tilde{M} = 0$ and the right one is the result of $\tilde{M} = 5\mu$. In the right, the colored with gradient is allowed region, and the brighter is the better.

we do a simple numerical analysis. In addition to that, we consider a general case for $\xi_{u,d}$. We do a numerical analysis varying $\frac{\tilde{M}}{\mu}$ and $\frac{A_u}{\mu}$, then search for the valid region, which satisfies the boundary conditions. In Fig. (3) we collected the valid points which satisfy at least the low energy requirements and $\left|\frac{B\mu}{\mu^2}\right| < 0.01$. The bright part is the allowed region in the previous analysis. Here we see that the variation on \tilde{M} and ξ_u is restricted by the boundary conditions. If Λ_{CFT} is as low as 10^8GeV , the result is slightly deformed. But the conclusion that we can find the parameter region, where the low energy requirements are satisfied with appropriate $\frac{\tilde{M}}{\mu}$ and $\frac{A_u}{\mu}$, is not changed.

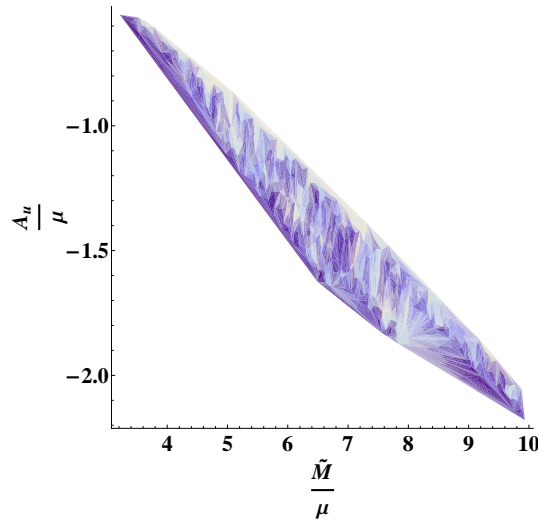


Figure 3: The region which satisfies the boundary conditions at the electro weak scale and Λ_{CFT} . It is projected to the $\frac{\tilde{M}}{\mu}$ and $\frac{A_u}{\mu}$ plane.

4. Phenomenology

In the parameter space which passes the low energy requirement, we pick a typical point, and analyze it. As we discussed in the previous section, here we have three dimensionful parameters: Λ , Λ_{CFT} and \tilde{M} . In addition to them, we have 2 dimensionless parameter: $\tan\beta$ and $\frac{A_u}{\mu}$. These are under the control of the low energy constraints. Here we investigate the case

$$\Lambda = 1.52089 \times 10^5 GeV, \quad \Lambda_{CFT} = 10^{12} GeV, \quad \tilde{M} = 5\mu, \quad \tan\beta = 4.0, \quad A_u = -\mu. \quad (4.1)$$

χ_1^0	χ_1^+	\tilde{t}_1	\tilde{b}_1	\tilde{u}_L	\tilde{c}_L	\tilde{d}_L	\tilde{s}_L	\tilde{g}	h_0	H
378.3	393.3	785.7	802.0	9897.3	987.3	997.7	997.7	1119.3	111.98	1094.54
\tilde{d}_R	\tilde{s}_R	\tilde{b}_2	$\tilde{\nu}_\tau$	$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\tau}_1$	$\tilde{\mu}_L$	\tilde{e}_L	χ_2^0	A
1127.3	1127.3	1131.9	1085.7	1086.6	1086.6	1093.7	1093.4	1094.8	1216.7	1093.83
χ_2^+	χ_3^0	\tilde{t}_2	\tilde{u}_R	\tilde{c}_R	$\tilde{\tau}_2$	\tilde{e}_R	$\tilde{\mu}_R$	χ_4^0	H^\pm	μ
1221.5	1124.2	1454.6	1644.8	1644.8	2127.0	2128.0	2128.0	4052.3	1097.12	1224.4

Note that the lightest superpartner except gravitino is wino, and the lightest scalar partner is the lightest stop. This can be understood easily because we give a correction to the mass of bino. Adding this correction makes μ as large as few TeV therefore the absolute value of trilinear coupling grows as μ at Λ_{CFT} . Here we assume that the trilinear coupling generated by the messenger higgs coupling, so that the values of the trilinear couplings $A_{u,d}$ are obtained with an ambiguity $\frac{A_u}{A_d}$. If we look the RG flow of the trilinear coupling, A_u and A_d grow monotonically as we go down to the low energy scale. Moreover small $\tan\beta$ means that top yukawa coupling is large relatively to others therefore, large off diagonal term in the stop mass matrix makes stop lighter than any other scalar partners. Now we consider some physical constraints, especially the decay rate of the rare process $B \rightarrow X_s \gamma$ and the anomalous magnetic moment of muon. Here is our result at the point given in (4.1), using `microOmegas`[15].

$$(g-2)_\mu = 5.60 \times 10^{-11}, \quad (4.2)$$

$$Br(B \rightarrow X_s \gamma) = 3.69 \times 10^{-4}.$$

The anomalous magnetic moment of muon is reported to be $\Delta a_\mu = (30.2 \pm 8.7) \times 10^{-10}$ in [16], and the rare process $B \rightarrow X_s \gamma$ is reported as $Br(B \rightarrow X_s \gamma) = (355 \pm 24_{-10}^{+9} \pm 3) \times 10^{-6}$ in [17]. The LSP is definitely gravitino, though the gravitino receive the correction from the anomalous dimension of X . It is because the gravity contribution is not negligible if very large correction is applied to the gravitino mass as shown in (2.4). As we accept large Λ , the masses are increased. If we take the anomalous dimension effect on gravitino into consideration, the gravitino remains to be the LSP.

5. Conclusion

The idea using the hidden sector dynamics to solve $B\mu/\mu$ problem in GMSB is quite simple and natural. However, it needs some modification to get a physical solution. There might be a number of ways to circumvent this situation. We propose a simple method via five dimensional setup, which

includes a bulk CS interaction between two $U(1)$ gauge fields. Within a reasonable parameter region, we get a physical solution. The typical region appears to have small $\tan\beta$, which is near 4.

Acknowledgments

We thank to H.D. Kim and D.Y. Kim for useful discussion. This work was supported by the Korea Research Foundation grants (KRF-2008-313-C00162).

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